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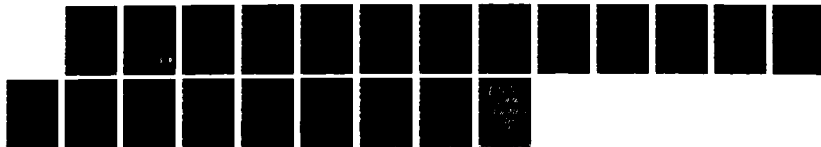
SOLID MECHANICS RESEARCH FOR QUANTITATIVE
NON-DESTRUCTIVE EVALUATION(U) NORTHWESTERN UNIV
EVANSTON IL DEPT OF CIVIL ENGINEERING J D ACHENBACH
AUG 87 N00014-85-G-0113

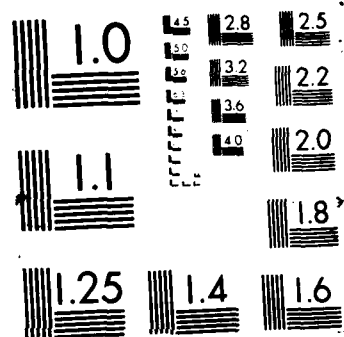
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FINAL REPORT

Project N00014-85-G-0113

Symposium on

SOLID MECHANICS RESEARCH FOR QUANTITATIVE
NON-DESTRUCTIVE EVALUATION

Sponsored by

Office of Naval Research

Mechanics Division

at

Northwestern University

September 18-20, 1985

Report prepared by

J. D. Achenbach

Department of Civil Engineering
Northwestern University
Evanston, IL. 60208
(312)491-5527

August 1987

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1. Introduction

Non-destructive evaluation (NDE) procedures play an important role in materials processing, as well as in subsequent material testing, product design, analysis of service-life expectancy, manufacturing, and quality control of manufactured products. They are also essential to on-line monitoring of the integrity of structural elements and complex systems. Rational accept and reject criteria should be based on NDE tests. Critical safety, efficiency and operational features of large-scale structures depend on adequate NDE capabilities.

The severe environment in which Naval structures may operate, together with the utilization of advanced materials, create a clear need for reliable methods of non-destructive evaluation. Flaws and defects are introduced into materials during processing and into structural systems during service. The presence of defects could severely hamper the structural integrity and effective performance of Naval systems. Improved methods for the detection and quantitative characterization of defects are, therefore, of great interest to the Navy.

The objectives of non-destructive evaluation frequently go beyond the detection of inhomogeneities. The capability to detect is a first and basic requirement. However, with the development of more sophisticated equipment and faster and more advanced signal processing methods, it has become feasible to detect very small inhomogeneities. Since some of these inhomogeneities may be harmless, it has become essential that test results make it possible to discriminate, for example, between cracks, pores and inclusions. Furthermore the effects of an inhomogeneity on the overall strength of a component depends not only on its mere presence and its

general nature, but also on its location, size, shape and orientation, and this information must also be obtained from the non-destructive test. This need for detailed information has given rise to a more rigorous and fundamental approach which is called quantitative non-destructive evaluation (QNDE).

Research in QNDE is typically concerned with quantitative relationships for the interaction of penetrating radiation with relevant material inhomogeneities (flaws, welds, cladding, grain structure, porosity, etc). These relationships are validated in model experiments, and they are then used to interpret measured data to establish the influence of potentially dangerous inhomogeneities on material and structural performance. Considerable interest lies in identifying and sizing microscopic or macroscopic flaws which would ultimately lead to failure. Other measurements of direct interest relate to residual stresses and material properties such as fracture toughness, preferably by direct methods.

Quantitative NDE spans such disciplines as mechanics of solids, materials science, electrical engineering, applied physics, applied mathematics and computer science. The ultimate aim is the prevention of mechanical failure. This aim is achieved by combining knowledge of the material state obtained by QNDE methods with considerations of the failure modes and information on the service conditions, to develop procedures to assess the safety of structural components, and to make a performance prediction. Hence, the component provided by solid mechanics plays a singularly important role. A proper understanding and exploitation of the interplay between detection and characterization methods with considerations of defect geometry, stress distribution, constitutive behavior and fracture mechanics is of the greatest importance.

The propagation of mechanical disturbances in solids and the conditions for failure of solid bodies are very active research topics in the general area of solid mechanics. They are also important components of the research program of the Mechanics Division of the Office of Naval Research. One of the aims of the Symposium was, therefore, to explore the contributions of solid mechanics research to QNDE, particularly to ultrasonic techniques. From a broader point of view, ultrasonic techniques have many advantages. They are relatively simple to apply, and mechanical waves can penetrate a material to substantial depth. Moreover, ultrasonic measurements of mechanical properties and defects are generally very directly related to useful life and eventual failure of a component.

Much work remains to be done before the methods of quantitative non-destructive evaluation will become fully implemented. At the present time the field is one of intensive research activity. Deficiencies still exist in many areas, including our ability to reliably interpret NDE measurements for the purpose of extracting quantitative information on defects and on the related failure characteristics of structural components and systems. Significant progress has, however, been achieved, and there is no doubt that important further advances are forthcoming. The Symposium presented an opportunity to take stock of the current state of the art in QNDE and to survey methods and techniques that are now being investigated, particularly with regard to ultrasonic techniques.

The presentations and backgrounds of the eighty-six participants of the Symposium reflected the interdisciplinary nature of work in QNDE. The organizers would like to thank the Chairmen of the Sessions:

L. E. Hargrove, J. A. Simmons, D. E. Eitzen, O. Buck, D. E. Yuhas,
W. A. Ellingson, Y. Weitsman, L. B. Welsh, A. V. Clark, Jr., and

S. K. Datta. The extended discussions during separately scheduled discussion sections were a special feature of the Symposium. The contributions of the leaders of these discussions: R. E. Green, M. Hamstad, D. O. Thompson, G. D. Sendeckyj, R. D. Weglein, J. E. Gubernatis, K. Salama, and G. C. Johnson, are gratefully acknowledged.

2. Program

The complete Program is listed in Appendix A.

3. Attendees

The meeting was attended by 86 engineers and scientists from universities, industrial organizations and government laboratories. The complete list of attendees is given in Appendix B.

4. Proceedings

The Proceedings have been published in book form entitled Solid Mechanics Research for Quantitative Non-Destructive Evaluation, (Editors: J. D. Achenbach and Y. Rajapakse), by Martinus Nijhoff Publishers. In the United States this publishing firm is represented by Kluwer Academic Publishers, P.O. Box 358, Accord Station, Hingham, MA 02018-0358, USA.

The title page and the Table of Contents are listed in Appendix C.

APPENDIX A

Symposium

on

SOLID MECHANICS RESEARCH FOR QNDE

September 18-20, Northwestern University

PROGRAM

Tuesday, Sept. 17, 1985

7:00-9:00 pm. Hospitality Room and Registration
Holiday Inn, Evanston

Wednesday, Sept. 18, 1985

8:30 am. Registration
Room G226, Nathaniel Leverone Hall
Northwestern University

**SESSION I
INTRODUCTORY**

J.D. Achenbach, Chairman

9:00 am. **Opening Remarks**
J.D. Achenbach, Northwestern University

9:05 am. Introduction
A. Kushner, ONR

**SESSION II
DOD INTERESTS IN QNDE
Y. Rajapakse, Chairman**

9:15 am. **Solid Mechanics Problems in QNDE**
W.R. Scott, Naval Air Development Center

9:50 am. **Naval Ship System Requirements in
Quantitative NDE**
R. deNale, Naval Sea Systems Command

10:25 am. **US Army Interests in Quantitative
Nondestructive Evaluation (QNDE)**
O.R. Gericke, U.S. Army Materials and Mechanics
Research Center

11:00 Coffee Break

11:15 am. **Air Force Requirements for NDE of Composites**
D.E. Chimenti, Wright-Patterson Air Force Base

SESSION III
ACOUSTIC EMISSION I
L.E. Hargrove, Chairman

- 11:50 am **Fundamentals of Acoustic Emission**
H.N.G. Wadley, National Bureau of Standards
- 12:30 pm. LUNCH, Allen Center

SESSION IV
ACOUSTIC EMISSION, II
J.A. Simmons, Chairman

- 2:00 pm. **Applications of Quantitative AE Methods:**
Dynamic Fracture, Materials and Transducer
Characterization
W. Sachse, Cornell University
- 2:40 pm. **On the Detection of Failure Mechanisms**
and Processes in Composites using
Acoustic Emission
J. Awerbuch, Drexel University

- 3:20 pm. Break

SESSION V
DEFECT CHARACTERIZATION BY SCATTERING METHODS
B.R. Tittmann, Chairman

- 3:40 pm. **Flaw Characterization by Ultrasonic**
Scattering Methods
J.D. Achenbach, Northwestern University
- 4:20 pm. **Experimental Research on Ultrasonic**
Scattering from Flaws
L. Adler, Ohio State University

SESSION VI
DISCUSSION
Holiday Inn, Evanston

- 7:30 pm. Discussors
G. Birnbaum, National Bureau of Standards
R.E. Green, The Johns Hopkins University
M. Hamstad, University of Denver
- 9:00 pm. Adjournment

Thursday, Sept. 19, 1985

SESSION VII
FRACTURE MECHANICS AND QNDE
O. Buck, Chairman

- 8:30 am. **Retirement for Cause Methodology**
Y.N. Yang, George Washington University
- 9:10 am. **Elastic Wave Interactions with Partially**
Contacting Surfaces: Application to
Fatigue Crack Characterization
R.B. Thompson, Ames Laboratory
- 9:50 am. **Ultrasonic Nondestructive Evaluation,**
Microstructure, and Fracture Toughness
Interrelations
A. Vary, NASA Lewis Research Center
- 10:30 am. Coffee Break

SESSION VIII
ACOUSTIC MICROSCOPY
D.E. Yuhas, Chairman

- 10:50 am. **Acoustic Microscopy for QNDE**
G.A.D. Briggs, University of Oxford
- 11:30 am. **QNDE Using Low-Frequency Acoustic Microscopy**
B.T. Khuri-Yakub, Stanford University
- 12:10 am. LUNCH

SESSION IX
QNDE OF COMPOSITE MATERIALS I
W.A. Ellingson, Chairman

- 1:45 pm. **Ultrasonic NDE of Composites as Inhomogeneous**
Media
Y. Bar-Cohen, Douglas Aircraft Company
- 2:25 pm. **Non-destructive Characterization of Damage**
in Graphite Epoxy Laminates
I.M. Daniel, Illinois Institute of Technology
- 3:00 pm. Break + Posters
For POSTERS PROGRAM, see separate sheet.

SESSION X
QNDE OF COMPOSITE MATERIALS II
Y. Weitsman, Chairman

4:00 pm. **Characterizing the Damage State of Composite Laminates via the Acousto-Ultrasonic Technique**
E.G. Henneke, Virginia Polytechnic Institute & State University

SESSION XI
DISCUSSION

4:35-5:30 pm. Discussors:
D.O. Thompson, Ames Laboratory
G.D. Sendeckyj, Wright-Patterson Air Force Base
R.D. Weglein, Hughes Aircraft Co.

6:30 pm. Cocktails, Holiday Inn

7:30 pm. Dinner, Holiday Inn

Friday, Sept. 20, 1985

SESSION XII
THERMAL WAVE IMAGING
L.B. Welsh, Chairman

8:30 am. **Thermal Wave Imaging for QNDE**
R.L. Thomas, Wayne State University

SESSION XIII
QNDE OF MATERIAL PROPERTIES AND RESIDUAL STRESS STATES I
A.V. Clark, Jr., Chairman

9:10 am. **Acoustoelasticity and Acoustoplasticity**
Y.H. Pao, Institute of Theoretical and Applied Mechanics, Taiwan

9:50 am. **Ultrasonic Measurement of Residual Stresses**
H. Fukuoka, Osaka University

10:30 am. Coffee Break

SESSION XIV
QNDE OF MATERIAL PROPERTIES AND RESIDUAL STRESS STATES II
S.K. Datta, Chairman

10:50 am. **Magnetic-Acoustic Technique to Measure Residual Stresses**
J.S. Heymann, NASA Langley

11:30 am.

**Ultrasonic Determination of Texture and
Stress in Metals**

C.M. Sayers, AERE Harwell

12:15

Lunch, Allen Center

SESSION XV
DISCUSSION

1:45 pm

Discussors

J.E. Gubernatis, Los Alamos National Laboratories

K. Salama, University of Houston

G.C. Johnson, University of California - Berkeley

3:00 pm.

Symposium Adjourns

APPENDIX B

LIST OF ATTENDEES

<i>Achenbach, J.D.</i> , Northwestern University	<i>Dundurs, J.</i> , Northwestern University
<i>Adler, L.</i> , Ohio State University	<i>Eitzen, D.G.</i> , National Bureau of Standards
<i>Angel, Y.C.</i> , Rice University	<i>Ellingson, W.A.</i> , Argonne National Laboratory
<i>Awerbuch, J.</i> , Drexel University	<i>Felsen, L.B.</i> , Polytechnic Institute of New York
<i>Bar-Cohen, Y.</i> , Douglas Aircraft Company	<i>Fukuoka, H.</i> , Osaka University
<i>Batra, N.K.</i> , Naval Research Laboratory	<i>Garroway, A.N.</i> , Naval Research Laboratory
<i>Bechtel, S.E.</i> , Ohio State University	<i>Gautesen, A.K.</i> , Iowa State University
<i>Briggs, G.A.D.</i> , University of Oxford	<i>Gericke, O.R.</i> , Army Materials & Mechanics Research Center
<i>Brock, L.A.</i> , University of Kentucky	<i>Goff, J.F.</i> , Naval Surface Weapons Center
<i>Buck, O.</i> , Ames Laboratory	<i>Green, R.E.</i> , Johns Hopkins University
<i>Budreck, D.E.</i> , Northwestern University	<i>Gubernatis, J.E.</i> , Los Alamos National Laboratory
<i>Chang, C.I.</i> , Naval Research Laboratory	<i>Hahn, T.H.</i> , Washington University
<i>Chiang, F.P.</i> , State University of New York	<i>Hamstad, M.</i> , University of Denver
<i>Chimenti, D.E.</i> , Wright-Patterson Air Force Base	<i>Hargrove, L.E.</i> , Office of Naval Research
<i>Clark, A.V., Jr.</i> , National Bureau of Standards	<i>Harris, J.G.</i> , University of Illinois-Urbana
<i>Cohen, J.K.</i> , Colorado School of Mines	<i>Henneke, E.G.</i> , Virginia Polytechnic Institute
<i>Daniel, I.M.</i> , Northwestern University	<i>Heymann, J.S.</i> , NASA Langley
<i>Datta, S.K.</i> , University of Colorado, Boulder	<i>Johnson, G.C.</i> , University of California, Berkeley
<i>Dayal, V.</i> , Texas A & M University	<i>Kamath, S.M.</i> , University of Illinois, Urbana
<i>Dempsey, J.P.</i> , Clarkson College	<i>Katz, E.</i> , Drexel University
<i>deNale, R.</i> , Naval Sea Systems Command	<i>Kechter, G.E.</i> , Northwestern University
<i>Djordjevic, B.</i> , Martin Marietta	
<i>Dunayevsky, V.</i> , Sohio Petroleum Company	

Keller, M., General Electric Corporation
Khuri-Yakub, B.T., Stanford University
Kinra, V.K., Texas A & M University
Kitahara, M., Tokai University
Kuo, M.K., National Taiwan University
Kupperman, D., Argonne National Laboratory
Kushner, A., Office of Naval Research
Matzkanin, G.A., Southwest Research Institute
Mendelsohn, D.A., Ohio State University
Mikata, Y., Northwestern University
Mura, T., Northwestern University
Nayfeh, A., University of Cincinnati
Norris, A.N., Rutgers University
Ohira, T., Cornell University
Pao, Y.H., Cornell University
Prine, D.W., GARD Division, Chamberlain National
Qu, J., Northwestern University
Rajapakse, Y., Office of Naval Research
Roberts, R., Argonne National Laboratory
Rokhlin, S.I., Ohio State University
Rudnicki, J.W., Northwestern University
Sabina, F.J., National University of Mexico
Sachse, W., Cornell University
Salama, K., University of Houston
Sayers, C.M., University of Bath
Scott, W.R., Naval Air Development Center
Segal, E., Argonne National Laboratory
Sendeckiy, G.P., Wright-Patterson Air Force Base
Simmons, J.A., National Bureau of Standards
Sotiropoulos, D.A., Northwestern University
Thomas, R.L., Wayne State University
Thompson, D.O., Ames Laboratories
Thompson, R.B., Ames Laboratories
Ting, T.C.T., University of Illinois, Chicago
Vary, A., NASA Lewis Research Center
Wadley, H.N.G., National Bureau of Standards
Weaver, R.L., University of Illinois, Urbana
Weglein, R.D., Hughes Aircraft Company
Weitsman, Y., Texas A & M University
Welsh, L.B., Signal Research Center
Yang, J.N., George Washington University
Yuhas, D.E., Magnaflux Corporation

Solid mechanics research for quantitative non-destructive evaluation

Proceedings of the ONR Symposium on Solid
Mechanics Research for QNDE, Northwestern
University, Evanston, IL, September 18–20, 1985

Edited by

J.D. Achenbach

*The Technological Institute
Northwestern University
Evanston, IL, USA*

Y. Rajapakse

*Mechanics Division
Office of Naval Research
Arlington, VA, USA*

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National Bureau of Standards,
Boulder, Colorado

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
<p>This is a final report of the Symposium on Solid Mechanics for Quantitative Non-Destructive Evaluation, which was organized at Northwestern University, September 18-20, 1985. The report contains an Introduction, a copy of the Program, a List of Attendees and the Table of Contents of the Proceedings. The Proceedings have been published under the title "Solid Mechanics Research for Quantitative Non-Destructive Evaluation" by Martinus Nijhoff Publishers.</p>		

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